URS

TECHNICAL MEMORANDUM

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SUBJECT: PANOCHHE ENERGY CENTER (PEC) PROJECT - GROUNDWATER MODEL.

1.0 INTRODUCTION

This report summarizes the results of a Physical Availability Demonstration for the PEC Well, which might be drilled to provide industrial supply water to the new Panoche Energy Center. In order to complete the Physical Availability Demonstration as efficiently and quickly as possible, URS constructed and utilized a steady-state groundwater flow model. The purpose of this report is to summarize the geologic and hydrogeologic factors that control groundwater flow in proposed Well area, and to demonstrate the quantity of local groundwater resources that will be available to meet the demands without negatively impacting surrounding well purveyors.

1.1 MODEL COMPONENTS AND STRUCTURE

The groundwater flow model for PEC needs the following data:

- Size of model domain;
- Size of model grid (finite-difference discretization);
- Number of model layers;
- Top elevation of model top layer (layer 1);
- Bottom elevation of each model layer;
- Initial heads across model domain (initial condition);
- General heads and conductance at particular model boundaries (boundary condition);
- Horizontal hydraulic conductivity/transmissivity;
- Vertical anisotropy ratio;
- Groundwater recharge rates and distribution;
- Pumping rates for wells;

- Definition of time parameters for simulation (steady-state);
- Parameters for output control; and
- Control parameters for the selected solver.

1.2 MODEL ASSUMPTIONS

Assumptions are often required for modeling because of the characteristics of governing equations, system complexity, limited availability of measured data, modeling objectives, and constraints of solution methods and computer systems. Because the model was developed for PEC groundwater system, several basic assumptions are specific to local conditions. Following are the initial model assumptions.

- Groundwater behaves in accordance with Darcy's Law;
- Horizontal hydraulic conductivity is isotropic;
- There is no groundwater movement through the base layer of the model; and
- Groundwater head is vertically uniform within a model layer.

Model assumptions may influence the accuracy and reliability of simulation results. Where possible, fewer simplifying assumptions should be made, to ensure the appropriate representation of the complex system. The closer the assumptions approximate the groundwater system and field conditions, the more accurately the model will predict the real conditions. However, certain assumptions are deemed necessary to develop a practical model to conduct simulation. The impact of model assumptions may or may not be quantifiable, depending on the characteristics of individual assumptions and the capability of the modeling software. A reasonable set of assumptions will create a model that is not too complex to be handled by the mathematical techniques, yet is sufficiently detailed to accurately represent the system. The assumptions described are reasonable and practical, based on field conditions and professional judgment. However, as new data become available, some of the initial assumptions could be modified after upgrading the model.

2.0 NUMERICAL MODEL

Model Code

The groundwater flow model was developed using the Brigham Young University Environmental Modeling Research Laboratory (EMRL) *Groundwater Modeling System* (GMS), Version 6.0 (EMRL, 2006). GMS is a comprehensive graphical user interface (GUI) for performing groundwater simulations. GMS provides a graphical preprocessor/postprocessor interface to several groundwater modeling codes including MODFLOW and MODPATH. The EMRL of Brigham Young University, in partnership with the WES, developed the GMS interface. The GMS was used to develop a site conceptual hydrogeological model and to convert it into groundwater flow model. A brief summary of all modeling codes used during this modeling effort are presented below.

MODFLOW Groundwater Flow Model. The computer code selected to model groundwater flow beneath the site was MODFLOW. MODFLOW is a 3-D, cell-centered, finite difference, saturated flow model developed by the United States Geological Survey (USGS) (McDonald and Harbaugh, 1988). GMS provides an interface to the updated version, MODFLOW 2000 (Hill et al., 2000). Based on the information available, the uncertainties in site-specific information, the hydrogeologic complexity of the site, and the modeling objectives, MODFLOW was considered an appropriate groundwater flow code.

MODPATH Particle-Tracking Model. Particle-tracking simulations provide a convenient means of visualizing groundwater flow paths. This is particularly useful for evaluating capture zones around a pumping well. MODPATH was selected as the particle-tracking program for this effort. MODPATH is a 3-D particle-tracking program that enables reverse and forward tracking from sinks (wells) and sources, respectively. MODPATH also was developed by the USGS (Pollock, 1994). GMS has updated the interface for MODPATH to a seamless module that couples with MODFLOW 2000. MODFLOW flow modeling results (direction and rates of groundwater movement) are among the inputs for MODPATH runs.

2.1 MODEL GRID

The model grid extends approximately 6 miles in an east to west direction, and approximately 6 miles in a north to south direction, a total area of 36 square miles approximately centering on PEC Well Site, as shown on Figure 1. The model is this large to ensure that any irregularities along the model edges, caused by a lack of data, do not affect model calculations in the area of interest—the proposed well site and a one- to two-mile area surrounding it. The model grid is aligned in a northeast-southwest direction, which corresponds with the regional groundwater flow direction. The model grid has been refined within the PEC area to more accurately simulate hydrologic stresses in the area of primary interest. The variable model grid is shown in plan view on Figure 2. The variable model grid cell sizes range from 20 by 20 foot cells to 200 by 200 feet cells. The smaller grid spacing was used around the proposed PEC well site to minimize numerical errors in the flow simulation. In addition, the variable grid size allows for finer resolution in areas of steep hydraulic gradients such as near pumping wells. The wider-spaced cells, located far away from the PEC area and near the model edges where less computation resolution is required, require less computer resources during simulations.

In plan view, the domain is spatially discretized into 95 columns in length and 81 rows in width. Vertically, the model extends to a maximum depth of approximately -1188 feet msl. The model is divided into three layers. These layers roughly correspond to monitoring zones beneath the site: Layer 1: Upper Hydrologic Zone (Upper Tulare); Layer 2: Aquitard (Corcoran Clay); Layer 3: Lower Aquifer (Lower Tulare). The correlation of model domain layers to monitoring zone layers are shown on Figure 3. Model layer 1 and 2 are simulated as unconfined aquifers, and Model Layer 3 is simulated as a confined aquifer.

2.2 MODEL BOUNDARY CONDITIONS

2.2.1 General Head Boundaries

General head boundaries were specified along the model's eastern, and western Boundary. A general head boundary is a leakage boundary through which a groundwater flux can move either into or out of the model.

2.2.2 No Flow Boundaries

As previously mentioned, the model domain was rotated so that the top and bottom model boundaries (in plan view) are parallel to the general groundwater flow direction. Since the top and bottom boundaries (in plan view) of the model domain are parallel to the general groundwater flow directions, the top and bottom boundaries were set as no-flow boundaries.

Boundary conditions in all three layers are the same and are presented on Figure 4.

2.3 GROUNDWATER LEVELS

The starting heads for the model were calculated from a recent groundwater investigation performed at PEC (URS, 2006) and local groundwater elevation maps (Westlands Water District, 2001). The Westlands Water District groundwater elevation maps were used to qualitatively check model results to ensure reasonable model-calculated directions of groundwater flow. Additional data used to construct the groundwater model were obtained from the Ground-water Flow in the Central Valley Report (Williamson et. al 1989).

2.4 HYDRULIC CONDUCTIVITY AQUIFER PARAMETERS

Several attempts were made to collect aquifer characteristic data from surrounding production wells and site-specific aquifer parameter data were very limited. Therefore, Initial estimates of hydraulic conductivity for model layers 1 through 3 were obtained from The US Geological Survey Professional Paper 1401-D (Williamson et. al 1989). Williamson et. al initial estimates of hydraulic conductivity for the Central Valley model were developed from aquifer test data, specific capacity data from area wells, recovery test data and particle size data from the USGS. These values were then adjusted during their model calibration process. According to Williamson et. al., Upper Tulare hydraulic conductivity values that range from 0.0053 to 110 feet/day with higher conductivity values corresponding to the coarser materials along major drainages. The Corcoran hydraulic conductivity values that range from 0.0053 to 1.1 feet/day with lower values generally corresponding to central basin areas where finer-grained (clay) sediments are located. The Lower Tulare sediments have hydraulic conductivity values that range from 1.1 to 110 feet/day

Model layer 1 and 2 were modeled as unconfined and Model layers 3 was modeled as a fully confined aquifer. Model layer 1 has hydraulic conductivity value of 10 feet/day. Model layer 2 has a hydraulic conductivity values of 0.0053 feet/day. Model Layer 3 has a hydraulic conductivity values of 100 feet/day. Vertical anisotropy ratios for the three model layers are as follows:

Layer 1 Kh/Kv = 10:1
Layer 2 Kh/Kv = 100:1
Layer 3 Kh/Kv = 10:1

2.5 VERTICAL GRADIENTS

Vertical gradients (potential for vertical flow) were calculated for several important reasons:

- Used to determine the potential vertical flow direction of groundwater
- It can reveal the hydraulic effects of groundwater pumping on different monitoring zones
- Is used as a tool to calculate groundwater elevations in areas where no current groundwater data is available.
- Used in the groundwater model to set-up initial boundary condition values.

Vertical gradients are based on depth-to-groundwater measurements collected from "cluster" wells (wells located radially within 50-feet of each other and screened in different monitoring zones) or "nested" wells (multiple wells in one borehole and screened in different zones). The head in the well within the deeper screen elevation minus the screen in the well with the shallow screen elevation divided by the vertical distance between the midpoint of the well screens of the two wells is used to determine the potential for groundwater to flow upward (positive gradient) or downward (negative gradient).

Ideally, several well pairs throughout an area will be used to calculate vertical gradients so an average vertical gradient can be computed. Unfortunately; because of limited access at the PEC site, vertical gradients were only available from the recent monitoring well install, so this data should not be considered an adequate representation of the entire area. Vertical gradients range from –0.0046 to 0.0020. Vertical gradient calculations indicate that there is an upwards gradient (positive) in the upper aquifer and downward (negative) gradient in the lower aquifer. Published data from Belitz and Heimes (1990) indicate that vertical gradients are variable depending where in the subsurface the wells are completed and also vary depending on the geologic environment.

2.6 RECHARGE

Recharge is the primary inflow model study area. Initial estimates of groundwater recharge were obtained from Rantz (1969). The components of groundwater recharge within the model study area do not include agricultural irrigation, urban irrigation, canal leakage, artificial lake seepage, and ephemeral stream infiltration.

2.7 PUMPING

Groundwater pumping represents the major outflow from the groundwater system within the model study area. Pumping from existing production wells are not simulated in the model as individual well screened intervals and pumping rates are not known. Attempts were made to contact neighboring well owners, but unfortunately specific well construction details and flow rates could not be acquired.

3.0 PHYSICAL AVAILABILITY ANALYSIS

The impact on the regional aquifers from groundwater pumping of the proposed PEC well to meet project water demands was evaluated. Following the completion of the steady-state groundwater flow model, several model simulations were run. To simulate the pumping from the proposed PEC well, the well was installed in Layer 3. The following is summary of those runs:

Simulation	Simulated PEC Pumping (Yes/No)	Pumping Rate (gpm)
1	No	N/A
2	Yes	750
3	Yes	1000
4	Yes	2000

3.1 SIMULATION 1

The model calculated groundwater surface contour map is illustrated for each layer (see Figures 5, 6 and 7). Note that the groundwater surface contour maps do not include the impacts of the proposed PEC well.

3.2 SIMULATION 2

The proposed PEC well pumped from Layer 3 at 750gpm (see Figures 8, 9 and 10). Note no noticeable drawdown occurs in any of the layers. The 750 gpm rate is the proposed pumping rate for the PEC well.

3.3 SIMULATION 3

The proposed PEC well pumped from Layer 3 at 1000 gpm. Note no noticeable drawdown occurs in any of the layers (see Figures 11, 12 and 13). The 1000 gpm rate is 33% more than the proposed pumping rate for the proposed PEC well.

3.4 SIMULATION 4

The proposed PEC well pumped from Layer 3 at 2000 gpm (see Figures 14, 15, and 16). Note less than 0.5 feet of drawdown occurs in Layer 2 (see Figure 15) and approximately 2 feet of drawdown was noticed in Layer 3 (see Figure 16). Comparisons between the 1000 gpm and 2000 gpm are presented on Figure 17. The 2000 gpm rate is 160% more than the proposed pumping rate for the PEC well.

4.0 LIMITED PARTICLE TRACKING ANALYSIS

Particles generated using MODPATH may be calculated to travel either forward (downgradient) through the model simulation or backward (upgradient from a specific point, such as an pumping well). Forward traveling particles provide information about the predicted route of groundwater over the model run. The particle starting locations are selected to predict groundwater migration from specific locations through time. Forward-traveling particles that are captured in an extraction well might not, however, predict the full capture zone for that well. They only predict the travel route for the particular starting location of the particle. Backward traveling particles predict where groundwater has traveled to reach a specific location. Particles traveling backward from an extraction well would predict the extent of that well's capture zone. Two separate predictive scenarios were conducted to evaluate where the groundwater being captured was coming from and to also see if the proposed PEC well will have a significant impact on the regional groundwater flow system in the lower aquifer.

Figure 18 shows the model results of "forward" predictive scenarios. Starting locations for the forward-traveling particles were set along the perimeters of the model area, the PEC well is pumping at 2000 gpm. Individual arrowheads along each particle path represent a 1-year time frame. As noted in Figure 18, there is no significant change in the regional groundwater flow regime.

Figure 19 shows the model results of the "backward" traveling particles. For backward particle tracking, particles are added at the well and the model is run to see what the proposed pumping influence would be on up gradient flow regimes and can also be used as a tool to estimate the zone of capture. The zone of capture for the PEC well pumping at 2000 gpm is approximately 270-feet wide. As with the forward particle tracking, individual arrowheads along each particle path represent a 1-year time frame.

It should be noted that in reality, the anisotropy of the aquifer and recharge characteristics would likely distort both of these scenarios.

5.0 SUMMARY AND CONCLUSIONS

A three-dimensional, finite-difference groundwater flow model was developed for the Panoche Energy Site in Fresno County, California. The model was developed using available historical information, PEC monitoring well installation data, and selected literature. The purpose of this model is to estimate the effects the future pumping of the proposed groundwater production well might have on Upper Tulare Aquifer, the Corcoran Aquitard, the Lower Tulare Aquifer, both local and regional flow regime and on surrounding wells.

Both the vertical gradient data (collected from the recent monitoring well installation) and hydraulic conductivity data (from published references) were used in the construction of the 3-D groundwater model. In summary, four groundwater-pumping scenarios (Scenario 1, no pumping; Scenario 2, pumping at 750 gpm; Scenario 3, pumping at 1000 gpm; Scenario 4, pumping at 2000 gpm) were incorporated into the model. Based on the predicted groundwater demand of the proposed facility, the proposed PEC well will be pumped at an average of 750 gpm. The Model run (Scenario 2) predict that if the well is pumped at 750 gpm, there will be no impacts (no drawdown) will occur in either of the aquifers. Even when the well is pumped at 1000 gpm (33% more than the proposed pumping rate) no noticeable drawdown occurs. Limited drawdown (less than 2.5 feet) occurs when the well is pumped at 2000 gpm.

Use of this model is considered adequate for screening purposes during this study. It is worth mentioning that a numerical model is a convenient and cost-efficient tool to mimic site conditions and to provide some difficult-to-attain insight into the groundwater responses under various natural and man-made conditions. However, any information obtained from modeling contains a certain level of uncertainty, especially for long-term predictions. Section 6.0 discusses uncertainty in greater detail.

6.0 MODEL USE, LIMITATIONS, AND UNCERTAINTY

This document and the model documented herein have been developed based on certain key assumptions made by URS, which substantially affect the efforts. These assumptions, although thought to be reasonable and appropriate, may not prove true in the future. Some of the data and assumptions have not been developed by URS have been accepted at face value. URS is not responsible for the validity or accuracy of non-URS information.

This document has been prepared by URS under the review of registered professionals. The model and this document are based upon URS interpretation of the available information. The interpretation and the conclusions drawn were governed by URS' experience and professional judgment.

This groundwater flow model can be a powerful tool, if used appropriately, to assist in making management decisions for the PEC groundwater program. Groundwater models are simplifications of the natural environment and therefore have recognized limitations. Hence, some uncertainty exists in the ability of this model to predict groundwater flow. Considerable effort was expended to minimize model uncertainty by using real-world values as model input whenever available and by conducting numerous model runs to calibrate and verify the model. Uncertainty of the model output reflects uncertainties in the conceptual model, the input parameters, and the ability of the mathematical model to simulate real-world conditions adequately.

The model uses steady-state flow conditions. It should be noted that no calibration was performed on this model other than visually comparing reference groundwater elevation contours from Westlands Water District to simulated heads. Additional data/model improvements required to vastly improve the current steady state flow model would include the following:

1. A well inventory would initially be performed and then the model results (simulated) could be compared/calibrated to observed well data.
2. Land Use would be incorporated into the Recharge values
3. Westland Water District groundwater contour maps for current conditions (2006) should be incorporated in to groundwater model for both upper and lower aquifer.
4. Water Purveyors in model domain could provide pumping rate data
5. Update hydraulic conductivity data with site-specific data.
6. If future modeling is required, a transient model could be developed using site-specific data including specific yield and specific storage values.
7. After the proposed PEC well has been installed, pumping test data could be incorporated in to this model and used as a tool to see how future pumping will influence local groundwater flow regimes.

7.0 REFERENCES

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